Diagnosis of Noise Sources on High-Speed Trains Using the Microphone-Array Technique

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Abstract: The abatement of wayside noise generated by high-speed trains requires a detailed understanding of the individual sound sources involved and of the noise-reducing measures available. To provide this information, the akustik-data Engineering Office has, over the past several years, been carrying out a large number of investigations on individual components of high-speed trains operated by the Deutsche Bahn AG. Sound sources are located and studied with array technology. The present paper gives a précis of microphone arrays and their practical application to railway noise. An example of measurements used to solve a particular problem is also included.

INTRODUCTION

To successfully and efficiently abate the wayside noise level generated by a high-speed train, it is necessary to know the locations and strengths of the individual sound sources and their relation to the total radiated noise. Further, the effect of abatement measures on individual sources has to be determined. To satisfy these criteria, the spatial resolution of the measuring equipment must be capable of isolating the important individual sound sources. This requirement can be fulfilled by a tailored microphone array positioned at the typical distance of 5 m from the track centerline. A single microphone cannot provide this resolution because of its omnidirectional directivity pattern. Its ability to separate neighboring sound sources can be improved somewhat by locating it closer to the track, but the microphone would then be in the near-field of lower-frequency sources. Furthermore, at roughly three meters distance from the track centerline, the microphone runs the risk of being within the turbulent boundary layer. In any case, however, the resolution cannot compare with that of a tailored array.

A FEW COMMENTS ON ARRAY TECHNOLOGY

The akustik-data Engineering Office has used variously configured microphone arrays to make measurements on numerous trains. These configurations include the one-dimensional line array mounted both vertically and horizontally, and two-dimensional arrays, i.e. cross or X configurations (1). In all cases, parameters for the usable frequency range are the array length and microphone separations, one from the other. Since this range generally encompasses only one to two octaves, it is advisable to mount several sub-arrays having different microphone spacings within a single line array. This so-called nested array provides a wider frequency range while maintaining high resolution with a minimum of microphones. When a two-dimensional sound-source distribution is required within a restricted frequency range, the X-array is useful (1).

When processing array data, it is essential to account for the propagation time of sound waves from the source to the individual microphones. For measurements on moving trains, the array's focus can be steered to track any point on the vehicle. This procedure not only increases integration time, but also eliminates the Doppler frequency shift (2). The results of the data processing are narrow-band FFT spectra at every point at which the beam was focused. For any desired frequency range, the resulting sound-source distribution can be given along the train in either a one or two-dimensional representation.

The selection of an appropriate array for a particular sound source (or sources) depends upon (i) whether or not there are significant near-neighbor sources and (ii) their spatial relationship to the positions of other sources. For example, consider rolling noise on passenger coaches. There are usually no significant sound sources lying in the vertical direction from the wheels, and a horizontal line array would be an appropriate configuration for such measurements. The situation is different for the head of a raised pantograph. In this case, there are generally no other sound sources lying at the height of the head. Hence, a vertical line array is appropriate for such an investigation. For more complicated source distributions, measurements can be made with either several differently oriented line arrays or a two-dimensional array.

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EXAMPLE OF USE

There are three categories of sound sources on a high-speed train, viz., the traction motors and cooling system, rolling effects, and aerodynamic interactions. Noise due to these sources has a category-specific dependence on train speed (3). As an example of sound in the third category, Figure 1 shows results representing the aerodynamic noise due to the head region of a raised pantograph on the forward power car of the German ICE/V (ICE prototype), measured with a nested vertical array at a passby speed of about 280 km/h. At high speeds, pantograph noise makes a significant contribution to the total wayside noise and hence had to be investigated.

![Diagram of sound levels in head region of a pantograph](image)

**FIGURE 1.** Sound-level distributions in head region of ICE/V pantograph in frequency range 2.7 to 3.1 kHz measured with a nested vertical array of 29 microphones; upper result: as-is, lower result: acoustically treated

The upper half of the Figure shows a result for the as-is pantograph. The spectrum measured at the coordinate of the head showed a strong, speed-dependent spectral peak. Wind tunnel tests demonstrated that this peak was caused by flow interactions with a small, cylindrical component on the head. Subsequently, various components of the pantograph, including the cylindrical one, were acoustically treated. In-situ array measurements of noise generated by this modified pantograph were then made. One of the results of these studies is given in the lower half of Figure 1. In both halves of the Figure, the frequencies are restricted to the range where the spectral peak lay. As can be seen, the sound-abatement measure had a significant effect.

Either as described above or in similar ways, all sound sources on a high-speed train can be investigated and their importance to wayside noise determined. If sources prove to be significant, appropriate abatement measures can be designed, installed, and, using array technology, tested.

REFERENCES


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